CLAIMS

I claim:

1. A method for estimating the maximum discharge power of a battery comprising:

calculating a maximum discharge current of said battery based on voltage limits of said battery;

calculating said maximum discharge power based on said maximum discharge current value.

2. The method of claim 1 further comprising:

calculating a maximum discharge current of said battery based on state-of-charge limits of said battery;

calculating a maximum discharge current of said battery based on current limits of said battery,

wherein said maximum discharge power is calculated from a minimum value of discharge current chosen among said calculated maximum discharge current based on voltage limits, said calculated maximum discharge current based on state-of-charge limits, and said calculated maximum discharge current based on current limits.

3. The method of claim 2 wherein said estimating of maximum discharge power takes into account a user-defined horizon of Δt.

4. The method of claim 2 wherein said step of calculating maximum discharge current of said battery based on state-of-charge limits obtains a state-of-charge by using a Kalman filtering method.

5. The method of claim 4 wherein an estimate of the uncertainty value yielded by said Kalman filtering method is used to find a confidence level of said calculated maximum discharge current.

6. The method of claim 2 wherein said battery is a battery pack comprising n cells.

7. The method of claim 6 wherein said step of calculating maximum discharge current of said battery based on state-of-charge limits calculates the current limits of each cell k in said battery pack using the equation

$$i_{\max,k}^{dis,soc} = \frac{z_k(t) - z_{\min}}{\eta \Delta t / C}$$

wherein $i_{\max,k}^{dis,soc}$ denotes the maximum discharge current based on state-of-charge, $z_k(t)$ denotes the cell state-of-charge at time t, $z_{\min}$ denotes the state-of-charge design limit, η denotes the Coulombic efficiency factor, Δt denotes the time horizon and C denotes the cell capacity.

8. The method of claim 7 wherein maximum discharge current of said battery pack based on state-of-charge limits is

$$i_{\max}^{dis,soc} = \min_k \left(i_{\max,k}^{dis,soc} \right).$$

9. The method of claim 1 wherein said step of calculating maximum discharge current of said battery based on voltage limits uses a cell model.

10. The method of claim 9 wherein cell model is solved by a Taylor-series expansion.

11. The method of claim 9 wherein said cell model is solved by using a discrete time-state space model.

12. The method of claim 9 wherein said battery is a battery pack comprising n cells.

13. The method of claim 12 wherein said cell model is

$$v_k(t+\Delta t) = OCV(z_k(t+\Delta t)) - R \times i_k(t)$$

wherein $v_k(t+\Delta t)$ denotes the cell voltage for cell k for the time period t units into the future, $OCV(z_k(t+\Delta t))$ denotes the open cell voltage as a function of the state of charge z_k for cell k for the time period t units into the future, R is a constant that denotes the cell's internal resistance, and $i_k(t)$ denotes the cell current.

14. The method of claim 13 wherein said maximum discharge current based on voltage limits is obtained by solving, through Taylor-series expansion

$$i_{\max,k}^{dis,volt} = \left(\frac{OCV(z_k(t)) - v_{\min}}{\frac{\Delta t}{C} \left. \frac{\partial OCV(z)}{\partial(z)} \right|_{z_{k(t)}} + R^{dis}} \right)$$

wherein $i_{\max,k}^{dis,volt}$ denotes the maximum discharge current of cell k, R^{dis} denotes the internal discharge resistance of the cell, $\left. \frac{\partial OCV(z)}{\partial(z)} \right|_{z_{k(t)}}$ denotes the derivative of the open cell voltage with respect to the state-of-charge z, evaluated at the present state-of-charge level $z_k(t)$.

15. The method of claim 14 wherein said $\left. \frac{\partial OCV(z)}{\partial(z)} \right|_{z_{k(t)}}$ is computed by a table lookup of empirical data.

16. The method of claim 13 wherein said cell model is solved by using a discrete time-state space model.

17. The method of claim 16 wherein said discrete time-state space model is

$$x_k[m+1] = f(x_k[m], u_k[m])$$
$$v_k[m] = g(x_k[m], u_k[m])$$

wherein m denotes the discrete time sample index, $x_k[m]$ denotes the vector function of time and the state of the system, $u_k[m]$ denotes the input to the system and

includes cell current $i_k[m]$ as a component, and $f(\cdot)$ and $g(\cdot)$ are functions chosen to model the cell dynamics.

18. The method of claim 17 wherein said $u_k[m]$ inputs includes temperature.

19. The method of claim 17 wherein said $u_k[m]$ inputs includes resistance.

20. The method of claim 17 wherein said $u_k[m]$ inputs includes capacity.

21. The method of claim 17 wherein $i_{\max,k}^{dis,volt}$ is found by looking for i_k that causes equality in

$$v_{\min} = g(x_k[m+T], u_k[m+T])$$

wherein $g(x_k[m+T], u_k[m+T])$ finds the cell voltage Δt seconds into the future.

22. The method of claim 21 wherein said equality is found by a using bisection search algorithm.

23. The method of claim 17 wherein the equation $x_k[m+T] = Ax_k[m] + Bu_k[m]$ is linear, wherein A and B are constant matrices.

24. The method of claim 12 wherein said minimum value of discharge current is chosen by using the equation

$i_{\max}^{dis} = \min(i_{\max}, \min_k i_{\max,k}^{dis,soc}, \min_k i_{\max,k}^{dis,volt})$, wherein

$i_{\max}$ denotes said maximum discharge current based on current limits,

$\min_k i_{\max,k}^{dis,soc}$ denotes minimum of said maximum discharge current based on state-of-charge limits for each cell k,

$\min_k i_{\max,k}^{dis,volt}$ denotes minimum of said maximum discharge current based on voltage limits for each cell k.

25. The method of claim 24 wherein said maximum discharge power is calculated by solving

$$P_{\max}^{dis} = n_p \sum_{k=1}^{n_s} i_{\max}^{dis} v_k(t + \Delta t)$$

wherein $P_{\max}^{dis}$ denotes the maximum discharge power, n_p denotes the number of cells in parallel, n_s denotes the number of cells in series, $i_{\max}^{dis}$ denotes said chosen discharge current and $v_k(t + \Delta t)$ denotes voltage of cell k for the time period t units into the future.

26. The method of claim 25 wherein $P_{\max}^{dis}$ is approximated to be

$$n_p \sum_{k=1}^{n_s} i_{\max}^{dis} \left(OCV\left(z_k(t) - i_{\max}^{dis} \Delta t / C\right) - R^{dis} \times i_{\max}^{dis}\right)$$

wherein $OCV(z_k(t) + i_{\max}^{dis} \Delta t / C)$ denotes the open cell voltage as a function of the state of charge z_k for cell k at time t,

$i_{\max}^{dis}$,

Δt which denotes the time horizon, and

C which denotes the cell capacity; and

R which denotes the cell discharge internal resistance.

27. The method of claim 2 wherein any said state-of-charge limits, voltage limits, and current limits can be eliminated from said calculations by using positive infinity or negative infinity to represent said eliminated limits in said calculations.

28. The method of claim 2 wherein any said state-of-charge limits, voltage limits, and current limits is dependent on temperature.

29. The method of claim 2 wherein said calculated maximum discharge power is checked to ensure that it falls within power limits of said battery.

30. A method for estimating the minimum charge power of a battery comprising:

calculating a minimum charge current of said battery based on voltage limits of said battery;

calculating said minimum charge power based on said maximum discharge current value.

31. The method of claim 30 further comprising:

calculating a minimum charge current of said battery based on state-of-charge limits of said battery;

calculating a minimum charge current of said battery based on current limits of said battery,

wherein said minimum charge power is calculated from a maximum value of charge current chosen among said calculated minimum charge current based on voltage limits, said calculated minimum charge current based on state-of-charge limits, and said calculated minimum charge current based on current limits.

32. The method of claim 31 wherein said estimating of minimum charge power takes into account a user-defined horizon of Δt.

33. The method of claim 31 wherein said step of calculating minimum charge current of said battery based on state-of-charge limits obtains a state-of-charge by using a Kalman filtering method.

34. The method of claim 33 wherein an estimate of the uncertainty value yielded by said Kalman filtering method is used to find a confidence level of said calculated minimum charge current.

35. The method of claim 31 wherein said battery is a battery pack comprising n cells.

36. The method of claim 35 wherein said step of calculating minimum charge current of said battery based on state-of-charge limits calculates the current limits of each cell k in said battery pack using the equation

$$i_{\min,k}^{chg,soc} = \frac{z_k(t) - z_{\max}}{\eta \Delta t / C}$$

wherein $i_{\min,k}^{chg,soc}$ denotes the minimum charge current based on state-of-charge, $z_k(t)$ denotes the cell state-of-charge at time t, $z_{\min}$ denotes the state-of-charge design limit, η denotes the Coulombic efficiency factor, Δt denotes the time horizon and C denotes the cell capacity.

37. The method of claim 36 wherein minimum charge current of said battery pack based on state-of-charge limits is

$$i_{\min}^{chg,soc} = \max_k \left(i_{\min,k}^{chg,soc} \right).$$

38. The method of claim 30 wherein said step of calculating minimum charge current of said battery based on voltage limits uses a cell model.

39. The method of claim 38 wherein cell model is solved by a Taylor-series expansion.

40. The method of claim 38 wherein said cell model is solved by using a discrete time-state space model.

41. The method of claim 38 wherein said battery is a battery pack comprising n cells.

42. The method of claim 41 wherein said cell model is

$$v_k(t+\Delta t) = OCV(z_k(t+\Delta t)) - R \times i_k(t)$$

wherein $v_k(t+\Delta t)$ denotes the cell voltage for cell k for the time period t units into the future, $OCV(z_k(t+\Delta t))$ denotes the open cell voltage as a function of the state of charge z_k for cell k for the time period t units into the future, R is a constant that denotes the cell's internal resistance, and $i_k(t)$ denotes the cell current.

43. The method of claim 42 wherein said minimum charge current based on voltage limits is obtained by solving, through Taylor-series expansion

$$i_{\min,k}^{chg,volt} = \left(\frac{OCV\left(z_k(t)\right) - v_{\max}}{\frac{\eta \Delta t}{C} \left.\frac{\partial OCV(z)}{\partial(z)}\right|_{z_{k(t)}} + R^{chg}} \right)$$

wherein $i_{\min,k}^{chg,volt}$ denotes the minimum charge current of cell k, R^{chg} denotes the internal charge resistance of the cell, η denotes the Coulombic efficiency factor, $\left.\frac{\partial OCV(z)}{\partial(z)}\right|_{z_{k(t)}}$ denotes the derivative of the open cell voltage with respect to the state-of-charge z, evaluated at the present state-of-charge level $z_k(t)$.

44. The method of claim 43 wherein said $\left.\frac{\partial OCV(z)}{\partial(z)}\right|_{z_{k(t)}}$ is computed by a table lookup of empirical data.

45. The method of claim 42 wherein said cell model is solved by using a discrete time-state space model.

46. The method of claim 45 wherein said discrete time-state space model is

$$x_k[m+1] = f(x_k[m], u_k[m])$$
$$v_k[m] = g(x_k[m], u_k[m])$$

wherein m denotes the discrete time sample index, $x_k[m]$ denotes the vector function of time and the state of the system, $u_k[m]$ denotes the input to the system and includes cell current $i_k[m]$ as a component, and $f(\cdot)$ and $g(\cdot)$ are functions chosen to model the cell dynamics.

47. The method of claim 46 wherein said $u_k[m]$ inputs includes temperature.

48. The method of claim 46 wherein said $u_k[m]$ inputs includes resistance.

49. The method of claim 46 wherein said $u_k[m]$ inputs includes capacity.

50. The method of claim 46 wherein $i_{\min,k}^{chg,volt}$ is found by looking for i_k that causes equality in

$$v_{\max} = g(x_k[m+T], u_k[m+T])$$

wherein $g(x_k[m+T], u_k[m+T])$ finds the cell voltage Δt seconds into the future.

51. The method of claim 50 wherein said equality is found by a using bisection search algorithm.

52. The method of claim 46 wherein the equation $x_k[m+T] = Ax_k[m] + Bu_k[m]$ is linear, wherein A and B are constant matrices.

53. The method of claim 41 wherein said maximum value of charge current is chosen by using the equation

$$i_{\min}^{chg} = \max(i_{\min}, \max_k i_{\min,k}^{chg,soc}, \max_k i_{\min,k}^{chg,volt}),$$ wherein

$i_{\min}$ denotes said minimum charge current based on current limits,

$\max_k i_{\min,k}^{chg,soc}$ denotes maximum of minimum charge current based on state-of-charge limits for each cell k,

$\max_k i_{\min,k}^{chg,volt}$ denotes said maximum of minimum charge current based on voltage limits for each cell k.

54. The method of claim 53 wherein said minimum charge power is calculated by solving

$$P_{\min}^{chg} = n_p \sum_{k=1}^{n_s} i_{\min}^{chg} v_k(t+\Delta t)$$

wherein $P_{\min}^{chg}$ denotes the minimum charge power, n_p denotes the number of cells in parallel, n_s denotes the number of cells in series, $i_{\min}^{chg}$ denotes said calculated minimum charge current and $v_k(t+\Delta t)$ denotes voltage of cell k for the time period t units into the future.

55. The method of claim 54 wherein $P_{\min}^{chg}$ is approximated to be

$$n_p \sum_{k=1}^{n_s} i_{\min}^{chg} \left(OCV\left(z_k(t) - i_{\min}^{chg}\eta_i \Delta t / C\right) - R^{chg} \times i_{\min}^{chg} \right)$$

wherein $OCV\left(z_k(t) - i_{\min}^{chg}\eta_i \Delta t / C\right)$ denotes the open cell voltage as a function of

the state of charge z_k for cell k at time t,

$i_{\min}^{chg}$,

Δt which denotes the time horizon,

η_i which denotes the Coulombic efficiency factor, and

C which denotes the cell capacity; and

R^{chg} which denotes the cell charge internal resistance.

56. The method of claim 31 wherein any said state-of-charge limits, voltage limits, and current limits can be eliminated from said calculations by using positive infinity or negative infinity to represent said eliminated limits in said calculations.

57. The method of claim 31 wherein any said state-of-charge limits, voltage limits, and current limits is dependent on temperature.

58. The method of claim 31 wherein said calculated minimum charge power is checked to ensure that it falls within power limits of said battery.

59. A power estimating apparatus for estimating maximum discharge power of a battery comprising:

a voltage measurement means for measuring the voltage of said battery;

a temperature measurement means for measuring the temperature of said battery;

a current measurement means for measuring the current of said battery;

an estimator means for calculating maximum discharge power of said battery, wherein said estimator means uses measurements from said voltage measurement means, said temperature measurement means, and current measurement means and performs calculations to estimate maximum discharge power of said battery, said estimator means comprising:

means for calculating a maximum discharge current of said battery based on voltage limits of said battery;

means for calculating a maximum discharge current of said battery based on state-of-charge limits of said battery;

means for calculating a maximum discharge current of said battery based on current limits of said battery, wherein said maximum discharge power is calculated from a minimum value of discharge current chosen among said calculated maximum discharge current based on voltage limits, said calculated maximum discharge current based on state-of-charge limits, and said calculated maximum discharge current based on current limits.

60. The power estimating apparatus of claim 59 wherein said estimator means takes into account a user-defined horizon of Δt.

61. The power estimating apparatus of claim 59 wherein said means for calculating maximum discharge current of said battery based on state-of-charge limits obtains a state-of-charge by using a Kalman filtering method.

62. The power estimating apparatus of claim 61 wherein an estimate of the uncertainty value yielded by said Kalman filtering method is used to find a confidence level of said calculated maximum discharge current.

63. The power estimating apparatus of claim 61 wherein said battery is a battery pack comprising *n* cells.

64. The power estimating apparatus of claim 61 wherein said means for calculating maximum discharge current of said battery based on voltage limits uses a cell model.

65. The power estimating apparatus of claim 61 wherein cell model is solved by a Taylor-series expansion.

66. The power estimating apparatus of claim 61 wherein said cell model is solved by using a discrete time-state space model.

67. An power estimating apparatus for estimating minimum charge power of a battery comprising:

a voltage measurement means for measuring the voltage of said battery;

a temperature measurement means for measuring the temperature of said battery;

a current measurement means for measuring the current of said battery;

an estimator means for calculating minimum charge power of said battery, wherein said estimator means uses measurements from said voltage measurement means, said

temperature measurement means, and current measurement means and performs calculations to estimate minimum charge power of said battery, said estimator means comprising:

means for calculating a minimum charge current of said battery based on voltage limits of said battery;

means for calculating a minimum charge current of said battery based on state-of-charge limits of said battery;

means for calculating a minimum charge current of said battery based on current limits of said battery, wherein said minimum charge current power is calculated from a maximum value of discharge current chosen among said calculated minimum charge current based on voltage limits, said calculated minimum charge current based on state-of-charge limits, and said calculated minimum charge current based on current limits.

68. The power estimating apparatus of claim 67 wherein said estimator means takes into account a user-defined horizon of Δt.

69. The power estimating apparatus of claim 67 wherein said means for calculating minimum charge current of said battery based on state-of-charge limits obtains a state-of-charge by using a Kalman filtering method.

70. The power estimating apparatus of claim 69 wherein an estimate of the uncertainty value yielded by said Kalman filtering method is used to find a confidence level of said calculated maximum discharge current.

71. The power estimating apparatus of claim 69 wherein said battery is a battery pack comprising *n* cells.

72. The power estimating apparatus of claim 69 wherein said means for calculating minimum current of said battery based on voltage limits uses a cell model.

73. The power estimating apparatus of claim 69 wherein cell model is solved by a Taylor-series expansion.

74. The power estimating apparatus of claim 69 wherein said cell model is solved by using a discrete time-state space model.